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INTERSERVICE UTILITY HELICOPTER RELIABILITY AND MAINTAINABILITY COMPARATIVE ANALYSIS

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The conclusions and recommendations contained herein are concurred in by this Directorate. The application of the principles stated in this report will take advantage of the experience of the three services. A complete analysis of a common Air Force, Navy, and Army helicopter under monitorship of an intraservice Project Advisory Group is planned.

The technical monitors for this study were Mr. Howard M. Bratt and Mr. Gary R. Newport of the Military Operations Technology Division.

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Under Army Contract DAAJ02-71-D-0001, ARINC Research Corporation developed the procedures and tools to investigate the comparative reliability and maintainability (R and M) performance of Army, Air Force, and Navy helicopters on an interservice basis. This report presents a management summary of the approach taken to correlate and analyze the performance data on systems, subsystems, assemblies, and parts used in common by the

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three services, as well as data on common functional applications of equipments. The results of the investigation are also presented, with explanations of the performance differences and similarities.

The similarity in makeup of the services' Mission Design Series (MDS) helicopter systems would tend to cause similarity in R and M performance; however, many factors that influence these similar components cause their R and M performance to differ.

This study encompassed the development and implementation of the procedures for performing an interservice helicopter analysis on a very small selected sample of components from the Army's UH-1H; the Air Force's UH-1F, TH-1F, and UH-1P; and the Navy's UH-1E helicopters.

The comparative reliability and maintainability analysis has provided results that can influence the overall research and development programs of future helicopter designs. These results are in the form of potential areas for hardware improvement; software improvements in technical manuals; inspection, overhaul, and retirement requirements; and procedures for a continuous helicopter monitoring program to optimize the usable life of the aircraft and its components.

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INTRODUCTION

The objective of this reliability and maintainability analysis of interservice utility helicopters was threefold. The first was to develop the procedures and algorithms necessary to establish a baseline for evaluating the comparative reliability and maintainability (R and M) experience on common components and dissimilar components performing common functions in Army, Air Force, and Navy helicopters. This is covered in "Approach to the Analysis". The second objective was to conduct a limited comparative analysis and problem investigation employing data on selected utility helicopters of the three services to identify significant variances in R and M experience and to determine causal relationships (covered in "Comparative Reliability and Maintainability Analyses"). The third objective, covered in "Conclusions and Recommendations", was to develop recommendations for R and M improvement criteria as a demonstration of the potential value of the comparative interservice R and M data analysis approach to new helicopter development programs.

In the course of this effort, we visited a number of activities to solicit support and pertinent information for the interservice R and M study. These included:

- Headquarters, Air Force Logistics Command (AFLC)
- Headquarters, Strategic Air Command (SAC)
- Naval Air Systems Command (NAVAIR)
- Headquarters, United States Marine Corps
- Naval Material Command (NAVMAT)
- Maintenance Support Office of Naval Supply Center at Mechanicsburg (MSO-NSC)
- Army Aviation Systems Command (AVSCOM)
- USAAMRDL, at Fort Eustis
- U.S. Army Aeronautical Depot Maintenance Center (ARADMAC)
- Bell Helicopter Company (BHC)
- Selected operational and maintenance units of the three services

The interest and support received from these organizations made the successful completion of the effort possible.

APPROACH TO THE ANALYSIS

HELICOPTER SELECTION

Table I lists the current turbine-powered helicopter mission design series (MDS) considered as possible subjects for the comparative R and M analysis performance study.

TABLE I. HELICOPTER MISSION DESIGN SERIES

Mfr.	Desig-nation	Service(s)	Mfr.	Desig-nation	Service(s)	Mfr.	Desig-nation	Service(s)
Bell	UH-1A	A	Boeing-	CH-46A	M	Sikorsky	CH-3B	AF
	UH-1B	A/N	Vertol	UH-46A	N			
	UH-1C	A		RH-46A	N		SH-3A	N
	UH-1E	N		CH-46C	A		RH-3A	N
	UH-1F	AF		CH-46D	M/A		HH-3A	N
	TH-1F	AF		UH-46D	N		VH-3A	M/A
	UH-1L	N		CH-46E	M		SH-3D	N
	TH-1L	N		CH-46F	M			
	UH-1M	A					CH-3C	AF
	HH-1K	N		CH-47A	A/AF		CH-3E	AF
	UH-1P	AF		CH-47B	A		HH-3E	AF
				CH-47C	A		HH-3F	CG
	UH-1D	A/N/AF					HH-3G	N
	UH-1H	A	Hughes	OH-6A	A			
							HH-52A	CG
	AH-1G	A/M	Kaman	UH-2A	N			
	TH-1G	A		UH-2B	N		CH-54A	A
	AH-1J	M		UH-2C	N		CH-54B	A
	AH-1N	M		HH-2C	N			
				HH-2D	N		CH-53A	N
	UH-1N	M/N/AF		SH-2D	N		HH-53B	AF
							HH-53C	AF
	TH-57A	N		HH-43B	AF		CH-53D	M
	OH-58A	A		HH-43F	AF		CH-53E	N

The utility helicopters of the H-1 MDS selected for the comparative analysis were the UH-1H (Army); the UH-1F, TH-1F, and UH-1P (Air Force); and the UH-1E (Navy/Marine Corps). The primary reasons for selecting these helicopters were the significant population of helicopters for each MDS in use by the respective services and the relative similarity of their designs. Table II lists some of the characteristics that influenced the selection.

DATA ACQUISITION

The data used in the analysis were acquired from each service in three basic forms -- field-reported maintenance and flying-hour data, maintenance

TABLE II. SELECTED HELICOPTER CHARACTERISTICS

Design Characteristic	U. S. Army UH-1H	U. S. Air Force UH-1F, TH-1F, UH-1P	U. S. Navy/Marine Corps UH-1E
Engine	T53-L-13	T58-GE-3	T53-L-11
Power Plant Output (SHP)	1400	1325	1100
Rotor System Hub Model	Standard	Standard	540
Blade Length/Width	48'/21"	48'/21"	44'/27"
Fuel System	Standard and Crashworthy	Standard	Standard
Fuel Capacity (gal.)	220 and 209	245	242
Weight Empty (lb)	4973	4476	5140
Weight Gross (lb)	9500	9000	9500
Cargo Internal (cu ft)	220	140	140
Cargo External (lb)	4000	4000	4000
Mission Profiles	Troop Transport Medical Evacuation Armed Recon	Missile Site Support Special Operations Force	Armed Recon Administrative Lift Medical Evacuation Trainer
Environment	Combat Unimproved Landing Unhangared	Noncombat Improved Landing Hangared	Combat Unimproved Landing Unhangared
Length, Nose to Center Line of Tail Rotor	40' - 7-3/32"	40' - 4-13/32"	38' - 4-27/32"
Length, Nose to Center Line of Main Rotor	11' - 8-21/32"	11' - 6-13/32"	11' - 7-1/2"
Quantity in Service (Estimated)	2000	150	200

and part manuals, and work-unit-code manuals. Table III describes the data obtained, the overall quality of the data, and the use of the data in the effort.

The Army TAMMS data were taken from an analysis performed for AVSCOM by the Northrop Corporation under contract.* These data, covering a one-year period, were compiled by component Federal Stock Number (FSN) for all major components on the UH-1H helicopters receiving maintenance during the data period.

MASTER WORK UNIT CODE CROSS-REFERENCE INDEX

In order to conduct a comparison of the R and M performance of the systems, subsystems, assemblies, and parts of each service's helicopters, a cross-identification system is required. The material item identifiers considered were Work Unit Codes (WUC), Manufacturers' Part Numbers (P/N), Federal Stock Numbers (FSN), and noun nomenclature. The services' data systems showed little similarity in their treatment of any of these identifiers. The overall complexity of a helicopter, with its myriad of parts and pieces, and the different designs made it almost impossible to use the P/N, FSN, and noun-nomenclature identifiers. The WUC identifier was selected as the prime cross-reference among the Army, Air Force, and Navy helicopters. The similarity of application of the WUC system by the triservices is limited, and this limits the quantity of assemblies and parts in a helicopter for which cross-matches were obtainable among the triservices. Figure 1 shows how each service's WUC system is structured.

Army		Air Force		Navy	
XXYZZMMNN		XXYZN		XXYYYZZ*	
XX	Functional Group	XX	System	XX	System
Y	Section	Y	Subsystem	YYYZZ	Assembly/Part
ZZ	Installation/Assembly	Z	Assembly		
MM	Subassembly	N	Assembly/Part		
NN	Part Level				

*Navy WUC is usually five characters; however, seven characters are used if system is complex enough.

Figure 1. Interservice WUC Directory Structure.

The Army WUCs are developed and assigned at AVSCOM. The field-reported TAMMS data are screened for each unique part, assembly, etc., and a WUC is assigned. For this reason the Army WUC directory is very large. The individual WUCs are dependent upon the system, subsystem, etc., to which

*AVSCOM Contract DAA-01-71-C-0503 (P3L).

TABLE III. DATA ACQUISITION: SOURCE, QUALITY, USE

Data Type	Army	Air Force	Navy	Use
Field-Reported Maintenance Data	TAMMS*/RAMMIT Data reported by FSN. Data detail good on aircraft maintenance only. Data system used for man-hour accounting. Elapsed maintenance time not reported.	AFM 66-1** Data reported by WUC. Data detail very good. On/off aircraft maintenance data system not used for man-hour accounting. Elapsed maintenance time reported.	3-M† Data reported by WUC. Data detail good. On/off aircraft maintenance data system used for man-hour accounting. Elapsed maintenance time reported.	Develop R&M Indices
Data Period Flying Hours	1 Jan - 30 Dec '70 706,000	1 Mar '71 - 28 Feb '72 42,300	1 Dec '70 - Nov '71 9,950	
Technical Manuals	TM55-1520-210-20, Army Model UH-1D/Helicopters Organizational shop manual TM55-1520-210-34 Army Model UH-1D/H Helicopters DS & GS shop manual	T.O. 1H-1(U)F-2-1 USAF Models UH-1F, TH-1F, UH-1P Organizational shop manual T.O. 1H-1(U)F-2-2 USAF Models UH-1F, TH-1F, UH-1P Intermediate shop manual 1H-1(U)-6WC-Series	NAVAIR 01-110HCA-2, Navy Models UH-1E, UH-1L, TH-1L & UU-1K Helicopters Intermediate shop manual NAVAIR-01-110HCA-6 Series	Assign WUCs Compare Designs Evaluate Planned Maintenance
Parts Manuals	TM-1520-210-34P-1/2/3/4, IPB UH-1A, -1B, -1C, -1D, -1H Complete breakdown and a cross reference IPB to FSN	T.O. 1H-1(U)F-4, IPB UH-1F/UP, TH-1F Complete breakdown	NAVAIR 01-110HCA-4, IPB UH-1E/1L, TH-1L, HH-1K Complete breakdown	Assign WUC Compare Designs
Work Unit Code Manuals	None WUCs assigned by FSN at AVSCOM - WUC listing very large and cumbersome.	T.O. 1H-1(U)F-06 USAF Model UH/TH-1F, UH-1P WUC assigned in field. Listing small, not complete.	NAVAIR 01-110HC-8 U.S. Navy Series H-1 Aircraft WUC assigned in field. Listing small, not complete.	Develop Master WUC Cross-Reference Listing

*The Army Maintenance Management System (TM 38-750).
**The Air Force Maintenance Management System (AFM 66-1).
†Maintenance and Material Management (3-M) System.

the part belongs. The Air Force and Navy develop their WUCs prior to entry of the aircraft into their inventory. The maintenance unit assigns the most applicable code when work is accomplished. The Air Force and Navy have held the size of their WUC directories to a minimum to keep from overburdening the users. Each system has its advantages and disadvantages. The Army has a large, complex system requiring continuous update as parts are added or changed; however, it is more accurate, giving greater analytical detail, and the maintenance organization is relieved of the task of researching WUCs. The Air Force and Navy WUC systems are simple and require no updating; yet the user must assign the WUCs, and the analytical detail obtainable is limited to the detail of the WUC manual.

The Master Work Unit Code Cross-Reference Index was developed to relate the helicopter WUCs of the Army, Air Force, and Navy to those parts, assemblies, subsystems, and systems which could be equated. The Master WUC Index developed for this study is similar in structure to the Air Force WUC directory. The Air Force WUC was selected as the structural guide for the master WUC because it is the least complex of the three services' WUCs, containing the fewest characters. In addition, the manual contains the smallest number of line items in the complete code. Figure 2 is a sample of the Master WUC Cross-Reference Index with the individual services' counterpart WUCs for the Tail Rotor Control Cable installation.

The cross-referencing of the interservice WUC directories required the use of appropriate technical manuals (TM) and illustrated parts breakdown (IPB) manuals from each service. The WUCs were laid out by system, and the TMs and IPBs were used to cross-match the corresponding parts and assemblies. In many cases, it was necessary to combine several codes in one service's directory to directly match a single WUC in another service's directory. When all matches were made, accounting for all the WUCs, a master WUC was assigned to every entry to assure that no maintenance would be lost. The result was a master WUC directory of 330 codes corresponding to 2000 WUC-Army, 700 WUC-Air Force, and 800 WUC-Navy. The master WUC index was also developed to permit aggregation of all maintenance actions from the lowest level within a system to the next higher assembly, the assemblies to their appropriate subsystem, and all subsystems to the system.

DEVELOPMENT OF COMPARATIVE DATA BASE

The individual service data systems are capable of supporting relatively detailed considerations of equipment performance within the limitations of completeness and accuracy of reporting and adequacy of processing and interpretation. These data-collection and feedback systems of each service are also capable of providing information necessary for problem identification, definition, and analysis associated with the service's operational equipment. Each service utilizes its data systems to accomplish the above. Each has its own criteria, definitions, and methods for obtaining the desired results. To compare the systems of the three services, it was necessary to normalize their criteria, definitions, and methods so that unbiased reliability and maintainability indices could be developed.

Army WUC	Nomenclature	Air Force WUC	Nomenclature	Navy WUC	Nomenclature	M-WUC	Nomenclature
11I0000000	Functional Group II Flight Controls	14000	Flight Controls	1400000	Flight Controls	14000	Flight Controls
11I000000	Tail Rotor Control Cable Installation	14110	Antitorque Controls	1413000	Tail Rotor Controls	14100	Tail Rotor Controls
11I000001	Grommet					14100	" "
11I000002	Spacer					14100	" "
11I000003	Fairlead					14100	" "
11I000004	Coupling					14100	" "
11I000100	Cable Assembly	1411C	Tail Rotor Control	1413B00	Tail Rotor Control Cable Assembly	14160	Cable and Chain Assembly
			Cables and Chair	1413000	Tail Rotor Control Chain	14160	" "
11I000101	Shim					14160	" "
11I000102	Bolt					14160	" "
11I000103	Barrel					14160	" "
11I000200	Support Assembly			1413700	Tail Rotor Control Support Assembly	14100	Tail Rotor Controls
11I000300	Bellcrank Assembly	14111	Bellcranks	1413600	Tail Rotor Control Bellcrank	14140	Control Bellcrank Assembly
11I000301	Bushings					14140	" "
11I000400	Quadrant Assembly	1411F	Quadrant	1413A00	Tail Rotor Quadrant Assembly	14150	Quadrant Assembly T/R
11I000401	Shim					14150	" "
11I000500	Bracket Assembly					14100	Tail Rotor Controls
11I000501	Bolt					14100	" "
11I000502	Pin					14100	" "
11I000503	Pulley	1411B	Pulleys	1413E00	Tail Rotor Control Pulleys	14170	Control Pulleys T/R
11I000600	Tube Assembly	1411F	Control Tube	1413200	Tail Rotor Control Tube/Lever Assembly	14120	Control Adjust Assembly
11I000700	Lever Assembly					14120	" "
11I000800	Wire Rope Assembly					14100	Tail Rotor Controls

Figure 2. Excerpts of Master Work Unit Code (M-WUC) Cross-Reference Index, Tail Rotor Control Installation.

Navy Data Processing

ARINC Research Corporation has previously developed algorithms for processing Navy 3-M data into a comprehensive and accessible R and M parameter format.* The Navy raw 3-M data received on magnetic tape were first compiled into the UH-1E helicopter MDS category. These data contained all scheduled and unscheduled maintenance reported (i.e., on-aircraft, off-aircraft, or job-support record keeping) and the aircraft flying-hour records.

The outline of the ARINC Research 3-M MDCS data file format is shown in Figure 3. The total number of such records filed is limited only by the total length of tape available. Each record provides for the recording of 302 data elements in 1327 record positions. With this type of format, the data elements are readily available for automated selection to determine information about maintenance actions at any level of assembly.

FILE FORMAT OUTLINE - NAVY MAINTENANCE DATA COLLECTION SYSTEM (FILE MDCS-3M)

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
JCN Type Equip. Serial Number	Level-1 End Items Actions	Level-2 Major Components Actions	Level-2 Sub-assembly Repair Actions	Level-1 & Level-2 End of Period & Work Stop M.H.A. (Primary Work Centers)	Level-1 Trouble-shoot Actions	Level-2 Trouble-shoot Actions	Level-1 & Level-2 Assist. Work Center Actions	Level-1 & Level-2 End of Period & Work Stop M.H.A. (Assist. Work Centers)	Level-2 End of Period & Work Stop M.H.A. On Sub-Assembly Repairs	Record Residue (Over-flow) Indicator	Level-1 & Level-2 Technical Directive Compliance Data

Figure 3. Outline, ARINC Research 3-M MDCS Data File Record.

The Aircraft Statistical Data (ASD) flying-hour records, separated from the maintenance data, are compiled separately for use in the R and M comparative-analysis programs discussed later in this section.

Air Force Data Processing

Air Force AFM 66-1 system flying-hour records, on-aircraft maintenance data, off-equipment shop data, and on-equipment engine maintenance data were processed to form a standardized Air Force maintenance and flying-hour data file. Because of certain anomalies in the Air Force reported

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*ARINC Research Publication 983-02-1-1176, *Reliability, Maintainability, and Availability Characteristics of 1527 Baseline and Other Baseline Configurations of Radar Set AN/APG-59/AWG-10*, 13 June 1972, Naval Air Systems Command Contract N00019-71-C-0335.

data, it was not possible to develop a uniform maintenance-action record for each discrete maintenance action reported. The principal anomaly was the inconsistency in maintaining a unique Job Control Number (JCN) throughout a complete maintenance action (i.e., a component removed from the aircraft under one JCN, repaired in the shop under a second JCN, and reinstalled on the aircraft under a third JCN). Each reported maintenance record, therefore, was kept as a unique entity and compiled into a standard format for ease of screening and compiling in the R and M comparative-analysis program.

Army Data Processing

Army TAMMS/RAMMIT data on magnetic tape were not utilized in this study. Instead, the R and M indices needed in the comparative analysis were obtained from the results of a contract conducted by the Northrop Corporation for AVSCOM. The R and M indices were available for each unique FSN that received maintenance on the Army's UH-1H helicopter for the year 1970. If the data had been available, minimal data processing programs would have been required since AVSCOM preprocesses the raw field-reported data into complete maintenance events.

Standardization of Interservice Data

The Air Force and Navy data files were cross-matched against the detailed Master WUC Cross-Reference Index (if the Army data had been used, they would also have been subjected to the same processing techniques).

A master WUC was assigned to each unique Air Force and Navy data record by comparing the service's reported WUC with that service's WUC code listing on the master WUC index. The master WUC was then simply transposed onto an extended segment of the maintenance action record. In this way, all data to be processed in the comparative R and M analysis program had a master WUC.

The total number of Air Force and Navy aircraft flying hours was also tabulated from the segment of the record that contained the report. These totals were entered into the R and M program.

COMPARATIVE RELIABILITY AND MAINTAINABILITY ANALYSIS DISPLAY

The comparative R and M analysis algorithm utilized the three services' maintenance files with the assigned master WUC, and the total number of aircraft flying hours was directly inputted to calculate the R and M indices. A segment of each record was utilized to identify each discrete maintenance action, determining if it was an inspection or on-aircraft or off-aircraft maintenance, and the action that was taken in performing the maintenance. Table IV shows the segment of each service's data file utilized. The maintenance is totaled by each unique master WUC and displayed for each service by the total number of maintenance actions (MA),

the total number of man-hours (MMH), the man-hours per action (MMH/MA), the number of man-hours per 1000 flight hours (MMH/1000 FL-HR), and the number of maintenance actions per 1000 flying hours (MA/1000 FL-HR).

TABLE IV. INTERSERVICE MAINTENANCE DATA ANALYSIS TO EQUATE DATA VARIABLES

Army (TAMMS) Variables	Air Force (AFM 66-1) Variables	Navy (3M) Variables
Aircraft TMS (MDS)	Mission Design Series	Type Equipment (MDS)
A/C Serial No.	A/C Serial No.	A/C Serial No.
Echelon Code (Type Maintenance)	Type Maintenance	Type Maintenance
Date (Julian)	Date (Day, Month, Year)	Date Initiated (Day,Month,Year)
Work Unit Code	Work Unit Code	Work Unit Code
Action Taken Code	Action Taken Code	Action Taken Code
Failure Detection (WDC)	When Discovered Code (WDC)	When Discovered Code
Failure Code How Malfunction	How Malfunction Code	How Malfunction Code
Units Worked On	Units Worked On	Units Worked On
Man-hours	Man-hours	Man-hours
Owner Unit	Base	Organization Initiating Action
Document Number	Job Serial No.	Job Sequence No. & Suffix
Type Document Code	Record Layout Code	Original Document Designator
Service Designator	Service Designator	Service Designator

Maintenance was also aggregated from the individual parts to the assemblies, to the subsystems, and finally to the system level of the master WUC, with totals displayed at each level. A statistical analysis was performed against the reliability indices for each service to determine if the results of the Army, Air Force, and Navy differ. The display layout from the comparative R and M analysis program is presented in "Selection of Components for Analysis".

COMPARATIVE RELIABILITY AND MAINTAINABILITY ANALYSIS

SELECTION OF COMPONENTS FOR ANALYSIS

Eight components were selected from the comparative R and M analysis display of the field data; these are shown in Table V with the analytical results. These components are all dynamic. The selection was made to assure that any differences due to operation, environment, or design would be readily discernible. Selecting components such as skin, doors, and connecting links might not produce useful results in this limited analysis.

PROBLEM INVESTIGATION

For each component selected, the field-reported data were manually reviewed to identify any anomalies that might influence the results. At the same time, the types of maintenance, the causes, and the actions taken were scrutinized to identify any repetitious occurrences or errors that might influence the results.

Once it was determined that the data were not in error or questionable, an in-depth problem investigation was undertaken to determine what was causing the disparity in the R and M indices between the services and, if possible, the extent of its influence. The problem investigation was conducted in three steps. First, the individual helicopter MDS component designs were reviewed and analyzed at the manufacturer's facility -- Bell Helicopter Company (BHC), Fort Worth, Texas -- to identify any differences between the components.

This was followed by a survey of Army, Air Force, and Navy operational and maintenance units as follows:

<u>Army</u>

Aviation Division Organizational Maintenance Branch, Transportation Center, Fort Eustis, Virginia

First Air Cavalry Division, 145th Aviation Btn, Fort Benning, Georgia

<u>Air Force</u>

Strategic Air Command, 28th Bomber Wing, Helicopter Section, Ellsworth Air Force Base, South Dakota

Strategic Air Command, 319th Bomber Wing, Helicopter Section, Grand Forks Air Force Base, North Dakota

<u>Navy/U.S. Marine Corps</u>

U.S. Marine Corps, 16th Marine Air Group, Camp Pendleton, California

TABLE V. SELECTED COMPONENTS FOR COMPARATIVE RELIABILITY AND MAINTAINABILITY DISPLAY

Component/M-WUC	Army					Air Force					Navy				
	No* MA	Total* MMH	MMH/ MA	MMH/ 1000 FH	MA/ 1000 FH	No MA	Total MMH	MMH/ MA	MMH/ 1000 FH	MA/ 1000 FH	No MA	Total MMH	MMH/ MA	MMH/ 1000 FH	MA/ 1000 FH
Quadrant Assembly Tail Rotor/14150			4.2	0.2	0.0**	16	15	0.9	0.4	0.4	8	9	1.1	0.9	0.8
Swashplate and Support Assembly/14270			15.7	128.7	8.2	155	838	5.4	19.8	[illegible].7	83	538	6.5	54.1	8.3
Stabilizer Bar Assembly/ 15110			3.9	10.3	2.7	466	1854	4.0	43.8	11.0	271	770	2.8	77.4	27.2
Scissor and Sleeve Assembly/15140			8.0	28.2	3.5	205	1439	7.0	34.0	4.8	181	507	2.8	51.0	18.2
Tail Rotor Hub and Blade Assembly/15200			10.0	344.7	34.6	527	2699	5.1	63.7	12.4	498	1003	2.0	100.8	50.0
Main Input Quill Assembly/26121			7.7	5.4	0.7	33	277	8.4	6.5	0.8	39	308	7.9	31.0	3.9
Generators, Starter and Main/42110			4.5	1.8	0.4	513	1197	2.3	19.0	8.0	121	459	3.8	46.1	12.1
Booster Fuel Pump/ 46130			8.0	0.8	0.1	228	773	3.4	18.3	5.4	26	78	3.0	7.8	2.6

*Basic Army data from Northrop Corporation study indices were not available.
**Calculated Value is 0.04 MA/1000 FH.

The objective of the survey was to determine the types of missions flown, the environments, the periodic maintenance requirements, and the capabilities of the maintenance facilities. In addition, each unit visited was queried about problems associated with each of the selected components, including recurring malfunctions, the level of authorized repair, capability of personnel, modifications, damage potential resulting from outside causes, and any other parameter that might affect the component's R and M performance.

In addition, a visit was made to the Army Aeronautical Depot Maintenance Center (ARADMAC) to survey the condition of those components subject to Time Between Overhauls (TBO) and retirement requirements. The depth of the overhaul and condition of the material were of primary concern.

The investigation was considered complete only after each service's engineering, maintenance, logistic, and project managers for each MDS helicopter were contacted to verify the findings with the cognizant personnel. The procedures by which each service monitors the overall condition of its aircraft were also obtained.

RESULTS OF THE ANALYSIS

The results of the analysis to determine the differences or similarities in the R and M performance of like components on the triservice helicopters are presented in the following subsections for each of the eight components investigated. This section is concluded with a synopsis of general findings. These might warrant further investigation and consideration to improve the overall reliability and maintainability performance of helicopters in military service.

Tail Rotor Quadrant Assembly

The comparative analysis of the tail rotor quadrant assembly produced the results shown in Table VI.

Design. All MDS helicopters use the same design and have identical manufacturer's P/N and FSN.

Operation/Maintenance. The location of this component in the tail section affords protection from severe environmental conditions, and its operational stresses are minimal. Of the field personnel surveyed, no one could recall ever replacing a quadrant or knowing of one requiring replacement or maintenance.

Depot Overhaul. The quadrant assembly is not a Time Change Item (TCI). When the helicopter is overhauled completely at its IRAN (Inspect and Repair As Necessary), the quadrant is removed and inspected and repaired or replaced as necessary.

TABLE VI. ANALYSIS RESULTS, TAIL ROTOR QUADRANT ASSEMBLY			
Parameter	Army	Air Force	Navy
Maintenance Actions per 1000 Flight Hours	0.0*	0.4	0.8
Maintenance Man-Hours per 1000 Flight Hours	0.2	0.4	0.9
Maintenance Man-Hours per Maintenance Action	4.2	0.9	1.1
Overhaul Interval (Hours)	None	None	None
Retirement Interval (Hours)	None	None	None

*Calculated value is 0.04 MA/1000 FH.

Summation. The quadrant was selected for this study because all services use identical components and the results of the data analyses showed no significant differences in the R and M performance. The investigations supported these results, with the variation in the R and M performance attributed to the anomalies of the three data systems and the maintenance personnel's procedures and philosophies. Some of the more significant factors are described in the section entitled "Pertinent Results Not Identifiable to Selected Components".

Swashplate and Support Assembly

The comparative analysis of the swashplate and support assembly produced the results shown in Table VII.

Design. The Navy swashplate and support assembly design is a heavier design to handle the higher loads of the 540 main rotor system. The Army and Air Force designs are identical for the standard main rotor system. Complexity is the same for both designs.

Operation/Maintenance. This component does not present problems for any of the services' MDS helicopters. It is estimated that as many as 90 percent of the components are removed for TBO only. The assembly's primary maintenance requirement is lubrication at periodic inspections. The Army and Navy conduct more maintenance on this component than the Air Force because of the harsher environment in which they operate.

TABLE VII. ANALYSIS RESULTS, SWASHPLATE AND SUPPORT ASSEMBLY			
Parameter	Army	Air Force	Navy
Maintenance Actions per 1000 Flight Hours	8.2	3.7	8.3
Maintenance Man-Hours per 1000 Flight Hours	128.7	19.8	54.1
Maintenance Man-Hours per Maintenance Action	15.7	5.4	6.5
Overhaul Interval (Hours)	1100	1200	1100
Retirement Interval (Hours) (Support and Collector Levers)	3300	3600	1100 (Support Only)
Bolt-Replacement Interval (Hours)	600	600	1000

Depot Overhaul. The swashplate and support assembly has one limiting part -- the uniball bearing, which is field-replaceable. Apart from this bearing and the parts scheduled for retirement, 85 to 95 percent of the parts are returned to service. These percentages are estimates of the personnel performing overhauls at ARADMAC. The parts of the component being retired are not inspected, but, again, the overhauling personnel stated that their physical outward appearance was good to excellent.

Summation. The differences in maintenance rates between the Air Force and the Army and Navy are primarily attributable to the additional preventive maintenance of the latter two services necessitated by the harsher environment in which their helicopters operate. The higher man-hour expenditure rates are attributable to the fact that the Army and Navy still use their data systems for man-hour accounting, whereas the Air Force dropped man-hour accounting because of the bias it incorporates into the data system in man-hour reporting. The swashplate and support assembly warrants investigation into the extension of the TBO rate. As previously stated, in overhaul the uniball bearing is usually the only item showing significant wear, and it is field-replaceable.

Stabilizer Bar Assembly

The comparative analysis of the stabilizer bar assembly produced the results shown in Table VIII.

TABLE VIII. ANALYSIS RESULTS, STABILIZER BAR ASSEMBLY			
Parameter	Army	Air Force	Navy
Maintenance Actions per 1000 Flight Hours	2.7	11.0	27.2
Maintenance Man-Hours per 1000 Flight Hours	10.3	43.8	77.4
Maintenance Man-Hours per Maintenance Action	3.9	4.0	2.8
Overhaul Interval (Hours)	None	1200	None
Retirement Interval (Hours)	None	None	2200
Center-Frame Retirement (Hours)	None	3000	2200
Tube Retirement (Hours)	None	3000	2200

Design. The Army and Air Force have the same stabilizer bar assembly. The Navy has a heavier bar design to handle the higher loads of the 540 main rotor system. Complexity is the same for both designs.

Operation/Maintenance. The stabilizer bar assembly is inspected at preflight, daily, 25 hours, weekly, etc., because of its criticality to aircraft operation. The Navy was experiencing problems because of the conduct of periodic turbine compressor stall tests. These tests, eliminated during the data period, imposed severe stresses on the aircraft. A study performed by Bell Helicopter Co. (Report No. 204-100-060, dated 12 October 1971) documents this situation, with a recommendation to eliminate these tests.

The Air Force and Navy change the bearings if there is any movement in the stabilizer bar assembly. The Army policy is to grease the bearings if movement is minimal and the grease eliminates it; otherwise, they also change the bearings. Corrosion is the major problem and is the basis for the rigorous inspection requirements.

Depot Overhaul. The stabilizer bar is removed from the helicopter at its IRAN and, if not retired, is disassembled and overhauled. This entails magnafluxing all parts of the assembly. In most cases the stabilizer bar is badly corroded upon arrival at ARADMAC.

Summation. The difference in the maintenance rates of the stabilizer bar is partially attributed to the different maintenance philosophies followed by the operational units of each service. The Army makes some allowance for wear; the Navy and Air Force make absolutely none. The overstressing of the rotating and drive elements with the Navy's preflight compressor stall test affects the performance of this component, but the extent of its influence is difficult to assess. The

occurrence of detrimental operational requirements could be eliminated or minimized by having the manufacturer review all flight and maintenance procedures instituted by the services.

Corrosion of the stabilizer bar is the major problem, especially in the Navy, whose helicopters operate in a salt-air environment.

The overhaul and retirement rates for the stabilizer bar on the three services' helicopters differ significantly, as can be seen in Table VIII. The dissimilarity in these rates was investigated.

Each service's project engineering division was queried concerning the procedures used in assigning these rates. The methods were all the same, with reliance primarily on the Army and the manufacturer's initial establishment. Changes were then made to adjust the rates to account for the differing designs, missions, and maintenance requirements of the Air Force and Navy.

Another example of this dissimilarity in retirement rates is reflected in the swashplate support in the Army and Navy UH-1N helicopter: 3600 hours and 600 hours, respectively. A stress factor of six for the Navy may not be realistic, and a large saving could be realized if the rate could safely be extended.

Scissor and Sleeve Assembly

The comparative analysis of the scissor and sleeve assembly produced the results shown in Table IX.

TABLE IX. ANALYSIS RESULTS, SCISSOR AND SLEEVE ASSEMBLY

Parameter	Army	Air Force	Navy
Maintenance Actions per 1000 Flight Hours	3.5	4.8	18.2
Maintenance Man-Hours per 1000 Flight Hours	28.2	34.0	51.0
Maintenance Man-Hours per Maintenance Action	8.0	7.0	2.8
Overhaul Interval (Hours)	1100	1200	1100
Retirement Interval (Hours)	None	None	11000

Design. As with the stabilizer bar, the Navy 540 rotor system has a heavier scissor and sleeve assembly design than that of the Army and Air Force's standard main rotor system. Again, the complexity of the three designs is identical.

Operation/Maintenance. The scissor and sleeve assembly requires constant attention to the pivot bearings, splines, and short side bearing for all three services. This is necessitated by the type of movement and the stresses to which this item is subjected. Bearing wear is the primary cause of maintenance. The overall assembly has no major problems, and complete change other than at TBO is minimal.

Depot Overhaul. ARADMAC had just established an overhaul assembly section for the scissor and sleeve assembly. They had little knowledge of the material condition of this component other than that it appeared to be in satisfactory condition and the bearings needed replacement.

Summation. The scissor and sleeve assembly is subject to a continuous-change stress load when the helicopter is operating. The Navy UH-1E helicopters have the highest maintenance rate but the lowest man-hours per maintenance action on this component. The Navy's 540 main rotor system adds significantly greater stress than the standard main rotor, which would account for the higher maintenance rates on the gimbal bearings. The lower rate of man-hours per maintenance event for the Navy's assembly could not be explained since the two designs of the scissor and sleeve are of equal complexity. The logical explanation might be that, with the higher maintenance actions per 1,000 flying hours, the Navy mechanics are more familiar with the component and, therefore, are able to do their work more expeditiously.

Tail Rotor Hub and Blade Assembly

The comparative analysis of the tail rotor hub and blade assembly produced the results shown in Table X.

TABLE X. ANALYSIS RESULTS, TAIL ROTOR HUB AND BLADE ASSEMBLY

Parameter	Army	Air Force	Navy
Maintenance Actions per 1000 Flight Hours	34.6	12.4	50.1
Maintenance Man-Hours per 1000 Flight Hours	344.7	63.7	100.8
Maintenance Man-Hours per Maintenance Action	10.0	5.1	2.0
Overhaul Interval (Hours)	100	300	100
Retirement Interval (Hours)	1100	1200	1100

Design. The Navy's design is slightly different from those of the Army and Air Force. During the data period, a field change of the tail rotor hub for all services was in progress to change the dynamic loading from the hub retaining threads to a flange on the trunnion body.

Operation/Maintenance. Operationally, the tail rotor hub and blade assembly is most critical, with foreign-object damage the prime cause of premature removal and replacement. The Air Force mission and the improved landing zones make this problem almost nonexistent. The Army and Navy have a major problem with tail rotor damage, especially with those helicopters having gun mounts. The ejected shell casings strike the blades. The Navy tolerates no damage to the tail rotor hub and blade assembly, whereas the Army will fly with minor nicks and scratches if they do not affect overall aircraft performance.

The tail rotor hub and blade assembly is treated differently by each service with respect to the maintenance requirements imposed. The Air Force completely purges the grease in the hub every flying day. The Navy and Army perform this grease purge at the 25-hour periodic inspection. The Army and Navy remove the hub and blade assembly every 100 flying hours and send it to the intermediate maintenance facility for overhaul. There it is inspected; its bearings are replaced; it is magnafluxed and balanced; and it is returned to the user. The Air Force performs the same overhaul every 300 hours but does all the work at the organizational shop. The Navy extended the tail-rotor overhaul to 300 hours in 1973.

The excessive man-hour figure reported by the Army was investigated. The shop personnel's estimate of 2 to 4 hours for the removal and replacement did not agree with their records. It was discovered that the Army reports all man-hour expenditures associated with a maintenance action. This includes the time to study the technical manual and obtain the necessary tools, the time to transport the defective component to the intermediate maintenance facility and retrieve it after it is repaired or parts are obtained, and the time to clean up after the maintenance action is completed. The use of man-hour accounting to justify personnel complements also causes the reporting of higher than normal maintenance man-hours during periods of low shop backlog.

Depot Overhaul. When the helicopter comes in for IRAN, the tail rotor hub and blade assembly receives the same overhaul at depot as it does during the 100/300-hour periodic. It is not inspected if it is to be retired.

Summation. The differing maintenance philosophies of the three services, the use of man-hour accounting by the Army and Navy, and the combat environment of the Army and Navy helicopters caused the disparity in the R and M performance results. The Navy's recent change in the overhaul of the component to 300 flying hours is believed to be a decision that the Army should adopt if they have not already.

Main Input Quill Assembly

The comparative analysis of the main input quill assembly produced the results shown in Table XI.

TABLE XI. ANALYSIS RESULTS, MAIN INPUT QUILL ASSEMBLY

Parameter	Army	Air Force	Navy
Maintenance Actions per 1000 Flight Hours	0.7	0.8	3.9
Maintenance Man-Hours per 1000 Flight Hours	5.4	6.5	31.0
Maintenance Man-Hours per Maintenance Action	7.7	8.4	7.9
Overhaul Interval (Hours)	1500	1200	1100
Retirement Interval (Hours)	None	None	None

Design. Two basic input quill designs are used in the MDS helicopters selected for this study. The transmission on which the quill is mounted is a standard design. The Navy quill design has a retainer collar to secure it to the transmission, in which "O" ring seals are used in conjunction with the internal Garlock seal. The Air Force quill design is mounted directly onto the transmission (no collar) with one "O" ring seal to aid as backup to the Garlock seal. The Army uses both designs.

Operation/Maintenance. The main input drive quill experiences one problem -- oil leakage -- which constitutes the major reason for premature removal. Those which do not leak are almost always removed for TBO. The Army will tolerate a small amount of seepage from the "O" ring seal before they replace the unit. The Air Force and Navy replace the quill if any leakage appears.

The Garlock seal internal to the quill is the part that fails, allowing oil under pressure to reach the "O" ring seals, resulting in leakage. All of the services send the quills to the intermediate maintenance facility for repair of the Garlock seal. The user replaces the "O" ring only if it is faulty.

Depot Overhaul. The main input quill assembly is overhauled in the same shop as the transmissions and 42- and 90-degree gearboxes. The two primary reasons for overhauling the quill are the leakage of the

Garlock seal and the quill's reaching TBO. Very few parts in this assembly are rejected as unusable in reassembly. Eighty percent of the bearings are returned to service. This is true of all the gearboxes. It was observed that some gearboxes are received for overhaul, as a result of reaching TBO, with the bluing still on the gear teeth. Most damage of items received for overhaul results from improper removal and preparation for storage and shipment.

Summation. The significantly higher R and M rates of the Navy are partially attributed to the preflight compressor stall test, which subjects the entire drive train to a severe shock; the increased stress of the 540 main rotor system; and the prohibition of oil leakage.

The leakage of the Garlock seals is a major problem for all services for all the quills -- not only the main input quill. For future designs of helicopters, a serious effort should be undertaken to alleviate this problem.

The condition of the quill assemblies and gearboxes received for overhaul is in most cases good to excellent; this might warrant investigation of the possibility of increasing the TBO rates or going to on-condition maintenance.

Starter Generator, DC Generator, Alternator

The comparative analysis of the starter generator, dc generator, and alternator produced the results shown in Table XII.

TABLE XII. ANALYSIS RESULTS, STARTER GENERATOR, DC GENERATOR, ALTERNATOR

Parameter	Army	Air Force	Navy
Maintenance Actions per 1000 Flight Hours	0.4	8.1	12.1
Maintenance Man-Hours per 1000 Flight Hours	1.8	19.0	46.1
Maintenance Man-Hours per Maintenance Action	4.5	2.3	3.6
Overhaul Interval (Hours)	None	None	1000 Starter Generator, 2000 Alternator
Retirement Interval (Hours)	None	None	None
Brush Change Interval (Hours)	None	100	100

Design. The analysis included three basic generator types: the engine starter generator on all helicopters in the study, a dc generator on Army and Air Force helicopters, and an alternator on the Navy helicopters. The actual designs are different, and the location of the generator on the transmission varies from one service to the next. These differences and the impact, if any, on R and M performance could not be assessed.

Operation/Maintenance. The Air Force and Navy perform a 100-hour Time Compliance Inspection (TCI) of the generator brushes. The generator is sent to intermediate maintenance, where the brushes are changed and an 8-hour run-in is provided. The Army does not change the brushes and has no problem with the generators. The starter generator for all services stays with the engine when it reaches TBO.

The maintenance reports against these components were screened at the users' facilities, and it was obvious in several cases that the reports should have been against the generator drive quill, not the generator. The extent to which this occurred could not be accurately assessed, even upon detailed examination of the data used in this study.

Depot Overhaul. The generators are normally received in the overhaul shop as a result of the helicopter airframe's reaching its IRAN. They are cleaned and returned to service. Very few require major overhaul. A shop foreman stated that he had seen a few generators with more than 9000 flight hours.

Summation. The generators should be allowed to run to failure. Each helicopter has redundancy with the starter generator. The Air Force's and Navy's changing of brushes every 100 hours is a needless maintenance expenditure.

Booster Fuel Pump

The comparative analysis of the booster fuel pump produced the results shown in Table XIII.

TABLE XIII. ANALYSIS RESULTS, BOOSTER FUEL PUMP

Parameter	Army	Air Force	Navy
Maintenance Actions per 1000 Flight Hours	0.1	5.4	2.6
Maintenance Man-Hours per 1000 Flight Hours	0.8	18.3	7.8
Maintenance Man-Hours per Maintenance Action	8.0	3.4	3.0
Overhaul Interval	None	None	None
Retirement Interval	None	None	None

Design. Two basic designs of the booster fuel pump were in use during the data period: air driven and electrically driven. The Army uses one air-driven and one electric (dc) in the standard fuel system and two electric, one ac and one dc, in the crashworthy fuel system. The Air Force and Navy have two electric pumps, one ac and one dc, in their standard fuel system. Both pumps run at the same time except during engine start-up, when only the dc electric pump runs. The Army Modification Work Order (MWO) installing the crashworthy fuel system was initiated during the data period.

Operation/Maintenance. The booster fuel pump is not considered a problem equipment. The mode of failure is usually bearing seizure. Most of the experience is with the electric pumps since only a limited number of air-driven pumps are currently in use.

Depot Overhaul. The electric booster fuel pumps are sent to ARADMAC for rebuilding after failure; they are not overhaul items. Most failures are a result of moisture's entering the sealed housing, shorting the motor or ruining the bearings. The vacuum booster pumps had not been overhauled by ARADMAC; therefore, no information was available.

Summation. The booster fuel pump maintenance rate was not considered a problem by the services. The Army's low rate might be explainable by the fact that the fuel systems were being modified from the vacuum and electric pump standard system to the two-electric-pump crashworthy systems. This would place many new pumps on the helicopters that would take a substantial period of time to begin experiencing failure. Another possible cause of the Army's low maintenance rate is that the deterioration of the fuel pumps is not operation-related but real-time-related; i.e., the pumps deteriorate at a set rate regardless of usage. The Army, which accrues more flying hours per aircraft per unit of time, has the lowest rate; the Navy is second.

GENERAL OBSERVATIONS

In the course of the comparative analysis, observations were made and important information obtained that did not relate directly to the selected components.

Establishment of Component Time Between Overhaul Rates

The differing TBO rates for like or identical components on the triservice helicopter became apparent during the analysis. The procedure for establishing the TBO rate was therefore investigated.

Bell Helicopter Company establishes retirement rates for all critical components on the basis of test results. These are turned over to each service upon purchase of the helicopters. Each service has a Systems Engineering Division, which assigns the TBO rates. The assignment of these rates is based on many factors, including the following:

* Past experience from other, similar helicopters
* Mission requirements
* Maintenance requirements
* Engineering knowledge

The Army, as the largest purchaser of helicopters, is relied upon by the Air Force and Navy for establishing the baselines.

Lead-the-fleet aircraft are selected, and the operational history is monitored closely to determine if TBO rates have been set too high. If they have, they are lowered. The Air Force and Navy are notified by the Army if a component's TBO rate is being changed. The Air Force and Navy rely on the Army because they have small populations of aircraft in comparison with the Army. The changing of TBO rates was explored since it appears to be a very slow process. From the surveys conducted, it appeared that many components were being overhauled excessively, especially the gearboxes.

The three services do not aggressively pursue increasing helicopter TBO rates. Component TBO values are selected to assure aircraft safety within an optimum cost goal. Initial TBO values are usually conservative, and increases are a result of increasingly successful operation. The Army as procuring agent approves and recommends changes to other DoD services. The airframe manufacturer usually assumes the task of recommending TBO increases to the Army. Significant differences have been noted in the attitudes of airframe manufacturers toward increasing TBO rates. However, active and effective TBO monitoring is essential to achieving the maximum increase. A vigorous TBO review and assessment effort should be the Army's goal.

A procedure should be considered for every aircraft type purchased in large quantity by the military, with the aircraft closely monitored through inspections to determine the optimum TBO for every critical component. This type of program could optimize the life of each aircraft, minimizing maintenance and operating expenditures.

Inspection Requirements

The inspection requirements of the Army and Air Force are similar. Their periodic inspections are based on helicopter use, i.e., flying hours. A majority of the Navy's periodic inspections are based on calendar time. There are advantages and disadvantages to both systems.

When the aircraft are in a high-use situation (combat), the calendar-inspection concept might allow the material condition to degenerate, causing unscheduled maintenance to increase rapidly, whereas the flying-hour base would keep pace with use-related deterioration. For low-use situations, calendar inspections would assure that the aircraft were maintained, with environmental deterioration held to a minimum, whereas flying-hour inspections could allow the aircraft to go unchecked for

extremely long periods. It might be necessary to develop two concepts of maintenance or a combination of the two concepts based on operational/ maintenance trade-offs.

Man-Hour Accounting

The Army and Navy use their data systems for man-hour accounting; the Air Force does not. The data analyses showed the Air Force to have the lowest overall maintenance man-hour rates. Table V shows that the reported maintenance man-hours per maintenance action for the Air Force are less than the Army's for 6 of the 8 selected components. The Navy values for maintenance man-hours per maintenance action for the selected components are not indicative of the entire comparative analysis. The Air Force values are less than the Navy's for 55 percent of the master WUCs.

The use of a data system for man-hour accounting causes the expansion of maintenance time during slow shop periods, which obviously biases the data. Using the Army and Navy data systems for developing component maintainability indices will introduce unwanted bias.

Ideal Sample Population of Air Force Helicopters

The Air Force UH-1F helicopters at Ellsworth AFB and Grand Forks AFB were all purchased at the same time. Each base has retained its own helicopters by serial numbers, maintaining as closely as possible the same number of flying hours on each airframe. The result is that when a problem occurs because of wearout, all the aircraft in one operational unit soon experience the same problem. This suggests that this population of helicopters in an ideal environment, with fully qualified maintenance personnel maintaining them, is experiencing definite wearout trends.

CONCLUSIONS AND RECOMMENDATIONS

The analysis techniques developed in this study are valid for use in computing and comparing the reliability and maintainability performance of interservice aircraft. The applications of the techniques are limited only by the imagination of the analyst and the opportunities that occur to compare like equipments in different applications and unlike equipments in similar applications.

In the component R and M performance analysis and evaluation, utilizing the eight selected components, the following conclusions and recommendations are made:

- The Navy's 540 main rotor installation places additional stress on the drive train and the rotating flight systems. Several components, including the swashplate and support assembly, stabilizer bar assembly, and scissor and sleeve assembly, were redesigned to handle this additional stress. The transmission and drive-train components, including the main input quill assembly, were not redesigned to withstand the increased stress. The overall effect is poor R and M performance of the Navy's UH-1E helicopter. This can be attributed partly to the turbine compressor stall tests conducted; but even after this practice was discontinued, the overall performance of these components was poorer for the Navy than for the Army and Air Force. For any future helicopter designs, it is recommended that serious consideration be given to making special limited modifications for small-population end items, where lower R and M performance offsets the operational-performance advances.
- The main input drive quill assembly presents a continuous maintenance problem with leakage, as do the other transmission and gearbox quills. A criterion is needed for the military to specify the quantity of fluid leakage that can be tolerated before it is necessary to remove the component. In addition, for future helicopter designs, the quill assemblies should be subjected to a major design review to determine if the leakage problem can be minimized or eliminated.
- The overhaul and retirement intervals for several similar and identical components differ on the triservices' helicopters. This occurrence was partially responsible for the differing R and M performance of these components. The differences led to the investigation of the assignment of TBO and retirement rates. It was concluded that at the time the rates were established, the judgment and criteria used were sound. The programs to monitor those rates were developed primarily to assure that the rates were not set beyond the operational limits of the components. The components that outperformed the TBO rates (i.e., primary reason for removal is TBO) were given little consideration. Many components are being overhauled because of the TBO requirement when

their condition appears not to warrant the overhaul. A program should be undertaken to examine all existing TBO and retirement requirements on these helicopters to determine if they can be increased or placed on an on-condition maintenance status (removal only when maintenance is required). For future aircraft designs, a major program should be established early in the design phase of the aircraft to monitor selected lead-the-fleet aircraft. This might be similar to the U.S. Air Force C-130 Hercules program, which made it possible to maximize all critical-component operational cycles.

- The selection of components in this study was limited; yet the results obtained are extremely useful. It is recommended that the Army continue comparative-analysis efforts, expanding them not only to examine more components on the helicopters in this study but to compare like components on helicopters with completely different designs and missions. A program of this type should provide the capability to detect the strong points and the weak points in design, operation, and maintenance procedures. The best of each could be used for future helicopter research and development programs. The information provided could aid in maximizing the reliability and maintainability performance of all new designs.
- Each service has periodic inspections based on calendar time, flying time, or both. The Army and Air Force are primarily flying-time-based, and the Navy is primarily calendar-time-based. There are advantages to each. It is concluded that a combination of the two inspection procedures could optimize the maintenance schedule, aircraft availability, and detection of impending problems. A periodic inspection system should be based on helicopter usage vs calendar time and dynamic vs static components (wearout vs environmental deterioration).
- The Air Force policy of maintaining consistent airframe usage at Ellsworth and Grand Forks AFBs has provided a sample population of aircraft that exhibit definite component wearout trends. The use environment and the caliber of maintenance personnel enhance this favorable situation. An in-depth analysis of the complete operational history of these aircraft may provide failure and wearout distributions on mechanical equipments that might otherwise be obtainable only in a controlled laboratory environment.